Solar Energy 151 (2017) 68–81

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Contribution to the analysis of a stand-alone photovoltaic system in a desert environment

Omar Kebour [a,*], Amar Hadj Arab [b], Abdelkader Hamid [a], Kamel Abdeladim [b]

[a] Université de Saad Dahleb, Route de Soumaa, BP 270 BLIDA, Ouled Yaich 09200, Algeria
[b] Centre de Développement des Energies Renouvelables, CDER, BP 62 Route de l'Observatoire, Bouzaréah 16340, Algiers, Algeria

ARTICLE INFO

Article history:
Received 16 February 2017
Received in revised form 17 April 2017
Accepted 3 May 2017

Keywords:
Charge curve
Global and diffuse irradiance
Competitiveness of photovoltaic and Diesel

ABSTRACT

Electrification of rural population has been always a strategic decision for the counties with high potential in terms of solar energy. However, different renewable and sustainable energy technologies can be adopted for electrification including photovoltaic system, diesel or hybrid system (photovoltaic and diesel). However, the choice between these options is exclusively dependent on many factors including the reliability and the cost associated with these technologies.

This study aims to examine the reliability of the electrification of rural areas using a standalone photovoltaic (PV) system in a Sahara environment (Algerian desert). In order to assess the electrical performance of the photovoltaic system, an experiment is set up in the village of Fadnoun, which is located in 2100 km south of Algiers (Algerian capital). The experiment is carried out for one year and the reliability of the system together with the way in which this electrification influence the energy consumption the villagers are assessed. It should be noted that this is the first experimental study of this kind that has been carried out in Algeria.

In addition, a technical-economic analysis was conducted by taking into account many parameters including cont, nominal power, solar radiation, and low voltage length. The outcomes of this study can be used as a benchmark to assess the performance of renewable energy technologies in other rural areas and make an informed decision about the most appropriate technology for electrification in rural areas.

1. Introduction

Sahara regions receive a greater amount of energy that makes them as favorite locations to set up the photovoltaic systems. In order to ensure continuity of service, for a number of Algerian Sahara villages, two principal and independent energy supply solutions can be practically considered that include diesel generators and photovoltaic systems.

The main research question is to identify the most economical solution among diesel and PV for any given site.

It should also be pointed out that this method of segmentation is used within the Algerian National Electrical Grid Company "Sonelgaz Holding" as a dashboard to identify areas where the turnover is high, and where industrial customers sectors are segmented in relation to their sector of activity and the power available (PMD) (Sonelgaz Group, 2015, Activity report).

One of the early studies in this field was by Borel (1962) in order to develop a redistribution mapping of Algerian territory or zoning, it is based on hygrothermal considerations. In addition were reported for just one representative day.

In another study Hadj Arab et al. (1995) evaluated solar irradiation level in Algeria; four climatic zones were identified for a different clarity index based on energy factors such as solar irradiation at ground level and determination of the probability of loss, for a period of twelve months. The results of this study have shown that the effect of the micro climate is too great on the determination of climatic zones.

In an attempt to improve the accuracy of the numerical models in estimation of solar radiation, Benmouiza (2015) has developed physical and empirical models to estimate the hourly, daily and monthly solar radiation from multiple sources. The developed models are applied and tested for different climatic regions in Algeria and consequently a zoning map of solar radiation is proposed.

In another study, a numerical model for economic profitability of a photovoltaic pumping plant was developed by Bouzidi (2004). The outcomes of this numerical modelling demonstrated the importance of economic competitiveness in the selection of diesel engine system compare to photovoltaic in the field of water

* Corresponding author.
E-mail address: kebour.omar@yahoo.fr (O. Kebour).

http://dx.doi.org/10.1016/j.solener.2017.05.009
0038-092X/

Nomenclature

A_G	the total generator surface (m^2)
Apv, *Abat*	annuity factors respectively photovoltaic without battery and with battery
A_D, A_{BT}	operating annuity factor (D: diesel, BT: low voltage line)
Am	overall area of photovoltaic modules (m^2)
Ai	annuity factor for equipments i
A	discount rate
$B_h(\beta)$	direct component of irradiance beam (kW h/m^2)
$B_d(0)$	the daily horizontal direct irradiance (kW h/m^2/d)
$B(\beta)$	the direct radiation (kW/m^2)
$Boh(0)$	one hour horizontal irradiance (kW h/m^2)
Bo	solar constant (W/m^2)
Cs	capacity of the storage system (Ah)
C_{bat}	battery price (USD/Ah)
C_{pv}	cost of PV system without storage (USD/kW h)
C_{fuel}	fuel oil cost (USD/l)
Ci	the ith calculated value
D*n*	day number of the year
$D(\beta)$	diffuse radiation (kW/m^2)
$D_d(0)$	the daily diffuse horizontal irradiance (kW h/m^2/d)
$Dh(0)$	the hourly diffuse horizontal irradiance (kW h/m^2)
Dn	day number of the year
Di	the annual operating cost for component i (USD)
$EG(\beta, ti)$	daily solar irradiation (kW h/m^2/d)
Escj	average of the daily energy at the converter output (kW h/d)
Eecj	average of the daily energy at the converter input (kW h/d)
Emj	average daily radiation (kW/d)
E_{pm}	energy output of PV module (kW h)
E_{RImin}	total irradiance received on a tilted PV (kW h/m^2)
E_{pg}	energy produced by the PV subsystem (kW h/m^2)
Ecj	energy consumption by the load (kW h/m^2)
Edj	the daily energy delivered by the generator (kW h/m^2/d)
Epj	energy produced by the PV subsystem (kW h)
Eschj	charge energy of the storage system (kW h)
Edischj	discharge energy of the storage system (kW h)
E	the average annual electricity consumption (kW h)
Ec	the annual electricity consumption (kW h)
F_{CS}	correction factor
Fr	fill factor (%)
$G(\beta)$	global irradiation on a tilted surface (kW/m^2)
$G_d(0)$	the individual daily horizontal irradiance (kW h/m^2/d)
$Gh(0)$	the individual hourly horizontal irradiance (kW h/m^2)
$G(\beta, ti)$	irradiance on panels at ti instant (kW/m^2)
H_{pv}, H_{bat}	fraction of annual operating expenditure
H_D, H_{BT}	investment fraction devoted to annual expenditures
I_L	yield current due to charge carriers that occurs due to radiations (A)
I_D, I_{BT}	diesel generator and low voltage line investment L_{BT} (USD)
Ii	initial cost for equipment (i) (investment) (USD)
Kt	atmosphere clarity index
K_d	diffuse fraction
P	the average discounted cost of electricity
L_{BT}	low voltage line length (km)
M_i	ith measured value
Nm	the number of modules
Nms	number of series connected modules in each string
N_{bp}	number of strings made of
Nm	the number of modules
Ni	lifetime pan of the equipment i
$PG(ti)$	power generator delivered at t_i instant (Wp)
$PG(\beta, ti)$	power provided by irradiance on PV panels at t_i instant (W)
Pd	battery discharge rate (Ah)
PPV	peak power of photovoltaic system (kWp)
Pbat	battery capacity (Ah)
$R(\beta)$	reflected radiation or albedo (kW/m^2)
RMSE	root mean squared error (%)
Tc	cell temperature (°C)
Vm	average voltage of module (V)
Vt	average working voltage (V)
ηm	photovoltaic module efficiency (%)
ηc	inverter efficiency (%)
ηs	storage efficiency (%)
$\eta_G(ti)$	generator efficiency at t_i instant (%)
η_{mc}	daily average inverter efficiency (%)
ηr	regulator efficiency (%)
ηGs	efficiencies of all subsystems (%)
ρ	ground reflectivity
β	tilted angle
θs	incident angle (°)
θzs	zenith angle (°)

pumping. The adopted method was based on the calculation of the overall cost of the cubic meter of water pumped based on expressed needs (height, maximum speed, and irradiation).

In addition, a number of studies on hybrid renewable energy systems have been conducted in different parts of the world where hybrid photovoltaic systems with energy storage have been modeled. The outcomes of these studies showed that hybrid systems have enormous technical and economic benefits (Nfah and Ngundam, 2004).

In another study Adaramola et al. (2014) conducted a technical-economic analysis to assess the feasibility of the hybrid photovoltaic-diesel engine system in Ghana. Results of this study highlighted that technical, economic and environmental feasibility of the system for a context with a medium irradiation level and relatively low fuel cost.

Bortolini et al. (2015) used the same approach with complete environmental monitoring. The results of experiment were based on an analytic model together with the economic and the environmental models to compute the LCoE. A parametric tool, implementing such models according to the introduced energy flow control algorithm, varying the PV plant rated power. Taking into account the effect of the low-voltage grid (L_{BT}), they would have varied the low-voltage length of the network

Ismail et al. (2013a, 2013b) conducted a technical, conceptual and economic analysis for a complete hybrid system that includes photovoltaic modules, micro-turbines and batteries (as an emergency power source) for a remote community in the Palestinian territories. However, this work was limited to only one case

In an attempt to improve the accuracy of the numerical models in estimation of the energy performance and the competitiveness, Kumar and Manoharan (2014) have studied in the case of Tamil Nadu (India) for different climatic zones on the basis of the current net cost. The results of this study have shown that government subsidies are essential to attract interest in renewable energy because they require capital, where people are poor and therefore unable to bear.